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FUTURE COMBAT SYSTEMS VISION AND ACQUISITION FRAMEWORK

BY JAMES R. POLLARD BERNARD G. DUREN
COMBAT SYSTEMS DEPARTMENT

JANUARY 1993

NAVAL SURFACE WARFARE CENTER
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FOREWORD

Today, the naval surface warfare community faces a time of change and uncertainty. Changing world political and military conditions have caused the U.S. to adopt a new national security strategy and created a measure of change and uncertainty in regard to basic missions and roles of the U.S. Navy. At the same time, many believe we are entering an era of fundamental and rapid change in warfighting systems and methods.

If the U.S. Navy is to be equipped with affordable, usable, and effective combat systems, it is essential to pursue new ideas and strategies for accommodating change in combat system engineering and development. These ideas and strategies must provide for

- Further advances in system automation and integration to meet stringent control and reaction time requirements
- Life-cycle effectiveness gains through design for extensibility, reusability, and resource sharing
- Dynamic reconfiguration capabilities permitting improvements in system adaptability, reliability, and damage resistance

This report is the result of continuing efforts by the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) to accommodate a need for change in combat system engineering and development methods by fostering a disciplined and systematic approach to definition and development of new construction/upgrade options for combat systems of the post-2000 era.

Approved by:

L. M. WILLIAMS III, Head
Combat Systems Department

ABSTRACT

For an enterprise with lofty goals, plans must be formulated around a vision expressing the ultimate purpose and strategy of the enterprise. Such a vision brings the main factors governing conduct of the enterprise into focus and helps mobilize available resources to achieve success. Since the ultimate purpose of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) revolves around surface ship combat systems, our vision is one of future combat systems.

This report considers a vision framework for development of future surface ship combat systems that are ever more capable and affordable, incorporating new technologies, and supporting implementation of new naval maritime strategies. The structure of the report reflects our idea of what constitutes a useful vision. This involves at least four elements, which should form a consistent and balanced set:

- Information about end-use requirements for the combat system
- A functional model (or architecture) indicating how the system will carry out its tasks
- An organizational model indicating how system development tasks can be accomplished
- A resource architecture providing for generation and control of all capital resources needed to build the system—funding, technology, people, plant, and procedures

The report begins with a review of the work that has gone into creating a functional architecture for surface ship combat systems. The resulting *vision architecture* serves as a framework for engineering of future combat systems. It then proceeds to explore implications of that framework for the way in which we organize and do business in the development of advanced combat systems.

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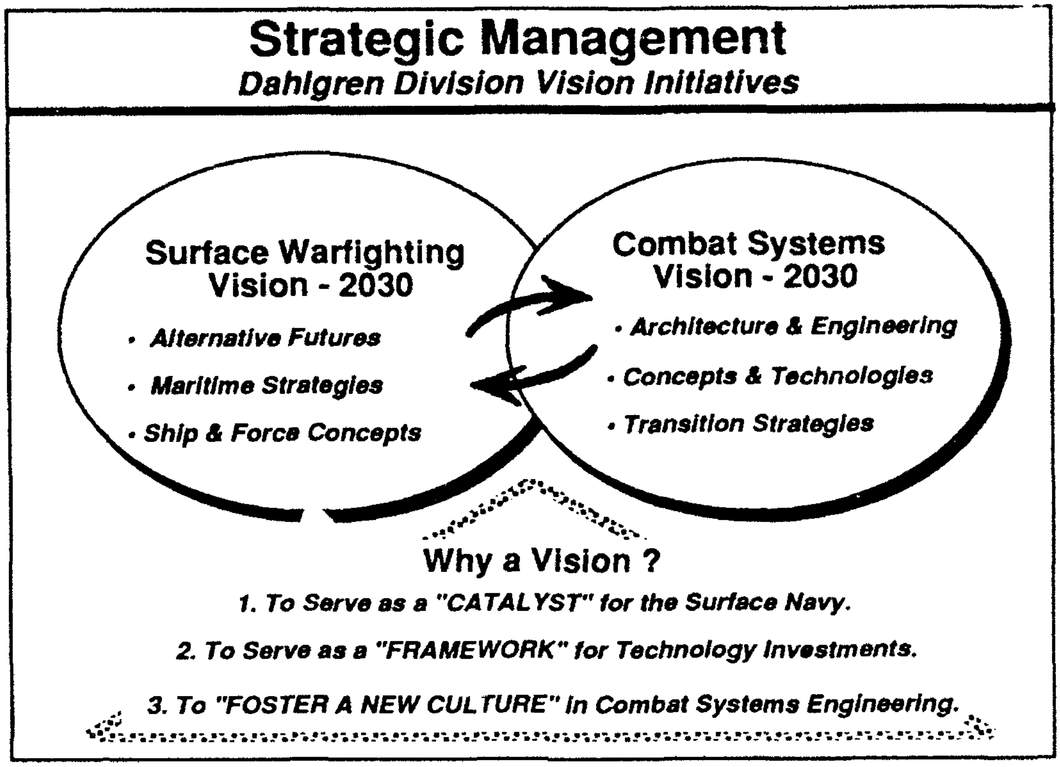
- Summary of Key Points

2030 VISION EFFORT

With the advent of the nineties, the naval surface warfare community found itself in a changing world. Changes in global political and military alignments were creating uncertainty in the future missions and roles of the U.S. Navy. Advances in technology, particularly in the computer-related fields, were placing increasing pressure on the extensibility of shipboard combat systems. Major shipbuilding programs were beginning to consider next-generation designs. Against this backdrop of uncertainty, the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) management decided to develop a *vision* of the future in combat systems for surface combatants. This section describes the approach taken in development of the vision architecture.

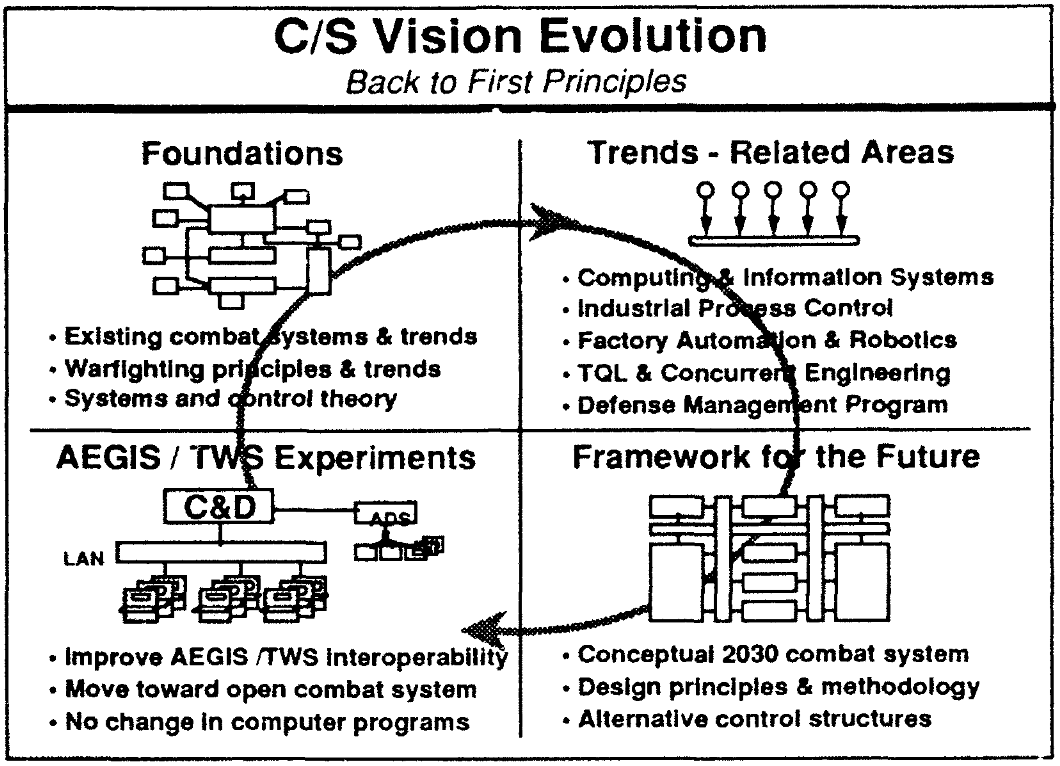


NSWCDD INITIATIVES

As the figure suggests, concepts for advanced combat systems must be shaped by consideration of future warfighting needs, as much as technology. We are following closely the evolution of Navy and Department of Defense (DoD) thinking on future warfighting goals and have also considered a set of alternative futures identified by the Division's warfare analysis activities.

Many ask why a 2030 time frame was chosen for this effort. Why not 2010, or even 2000? The answer is that a sizeable store of ideas and experiences from past and present work was accessible but the part of the store that is appropriate for reuse must be filtered out. In this context, 2030 makes a better filter than 2010 or 2000.

The team responsible for the combat systems part of the effort began several years ago to formulate a functional architecture as a key component of the vision. This architecture reflects emerging trends in naval warfare, combat systems, and technology. Status of this part of the effort is summarized in the next vugraph.



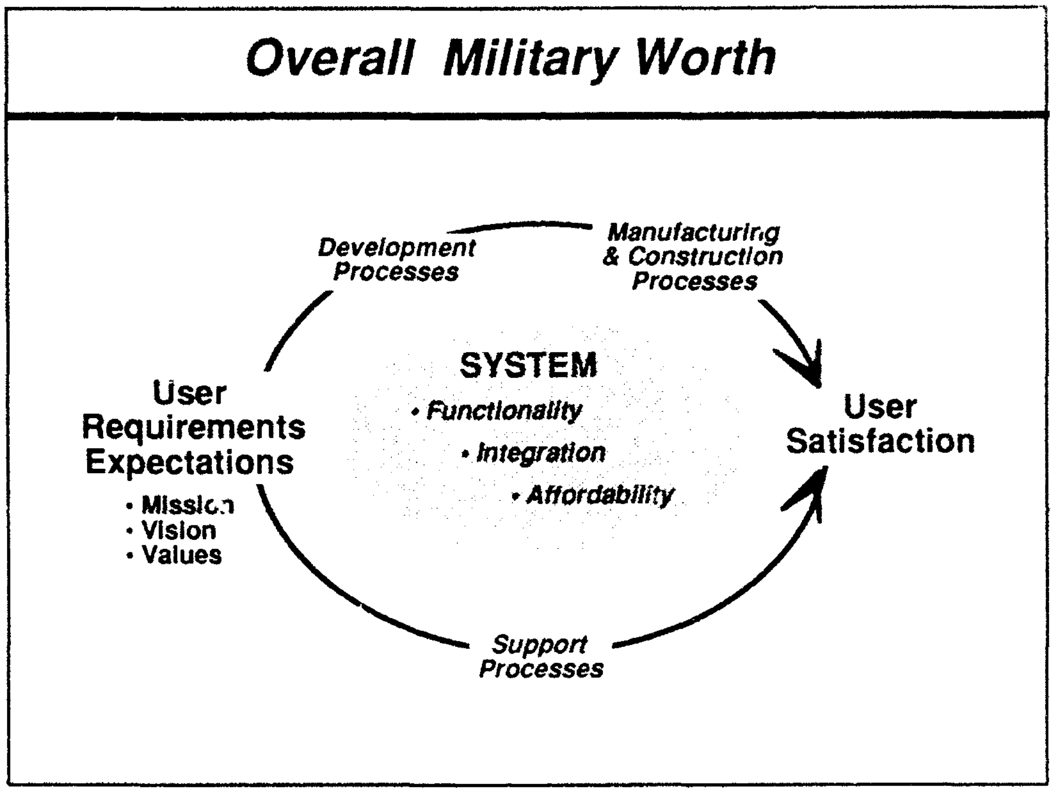
COMBAT SYSTEM VISION ELEMENTS

The effort started with a study of existing combat systems and how they are evolving (top left). This led to recognition of a de facto architecture that now prevails on surface ships. At the same time, strengths and weaknesses of the current architecture, projected into the future, were assessed. Areas of relative strengths include the horizontal or warfighting paths. Relative weaknesses include information management and control across the paths.

In addition, developments in such related areas as information systems, industrial process control, factory automation, and concurrent engineering have been examined to identify techniques and technologies that can be applied to the problems of combat system engineering (top right).

Next, a framework for future combat systems was derived (bottom right). This was based in part on efforts to overcome weaknesses and capitalize on strengths of the de facto architecture. Several technical reports articulating the results have now been published. We are continuing to identify alternative technologies and system concepts. In addition, several aspects of the architecture itself warrant further consideration.

The work has not been conducted in a purely theoretical context. Various laboratory experiments and demonstrations (bottom left) were conducted to determine the practicality of an evolutionary transition from existing combat system architectures to the vision architecture. Results indicate this transition can be achieved in a conservative manner, without any need to reinvent components that are already known to work well.



OVERALL MILITARY WORTH

The 2030 vision effort is regarded as a framework for dialogue on how to make future combat systems more capable and affordable. This demands attention to both product quality and process quality Product quality depends on functionality, affordability, and integration characteristics of the combat system delivered. Change drivers include new technologies and threats, as well as new maritime strategies. Process quality depends on arrangements for development, manufacturing, and support of the combat system. Change drivers include manufacturing technology (viewed broadly) and the military acquisition framework.

It is time for a new framework in combat system acquisition. Ideas about such a framework are based largely on theory but with some empirical support as well. The goal is to simply begin a dialogue on this important topic. The key questions are

- *Are we on the right track?*
- *How should we proceed?*

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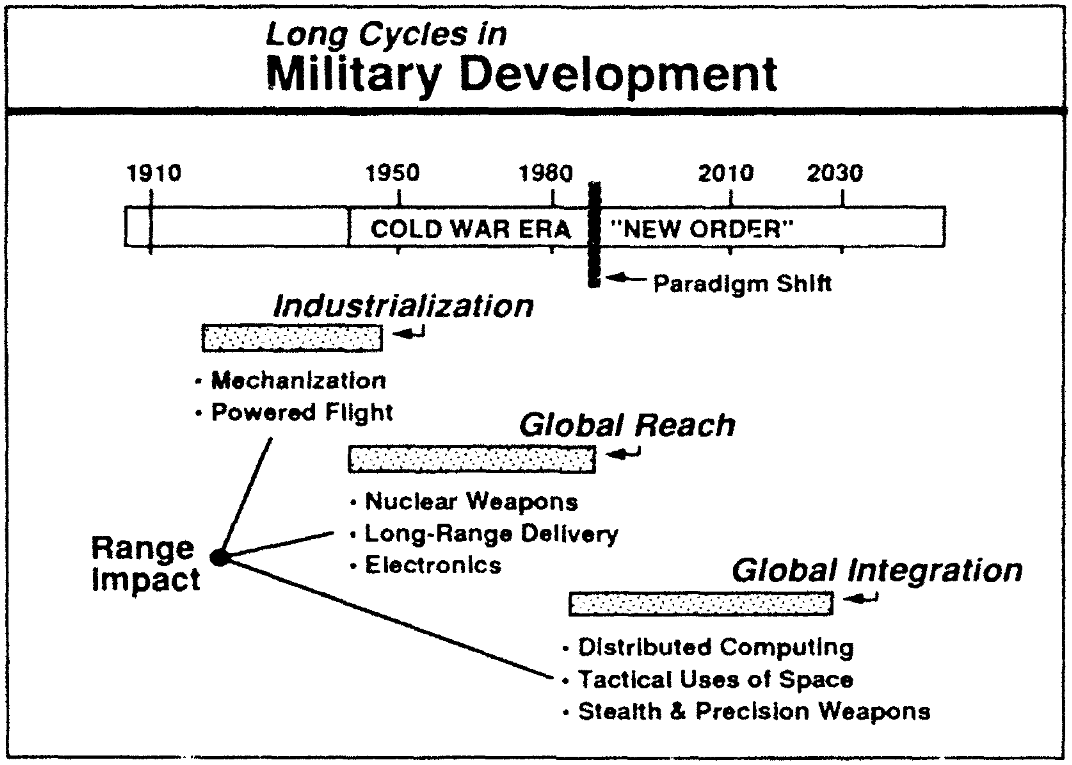
CHANGE DRIVERS

Operating concepts and capability goals for combat systems are based on expectations about future warfighting strategies, tactics, and technologies. This demands direct involvement by warfighters and depends on a degree of consensus about what is to be done.



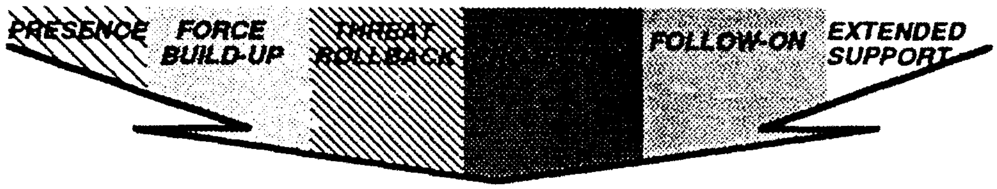
LONG CYCLES IN MILITARY DEVELOPMENT

Many believe we are entering into an era of fundamental change in warfighting systems and methods. This figure indicates the key features of the new era and relates them to past developments. This prospect has a major influence on our efforts to articulate a vision of future combat systems. The current cycle of austerity in defense will bring pressure to reduce the size, manning, and unit cost of surface combatants. Measures for achieving continuous improvement in cost/capability ratio may be a key factor in the struggle to balance warfighting capability and force planning considerations. Improvements in design for extensibility and interoperability are especially promising. Against this background, certain predictions about the course of surface ship combat system design can be made. The following have been given wide circulation by Navy leaders.

- Future ships will use integrated electric drive or the intercooled recuperative gas turbine engine but will use less space than current main engineering plants.
- Future combat systems may be as capable as DDG 51 but be considerably smaller in weight and footprint.
- Future combat information centers will have fewer people but permit improved flexibility and coordination. Automated decision aids will be used to sort friend from foe more with greater accuracy and efficiency.

Change Drivers

The Operational Environment



- **Complex Operating Constraints**

  Fight on TV -- Low tolerance for US losses or mistakes
  Limited sea room and constrained battle space

- **Flexibility and Adaptability in Operations**

  Joint and Combined Operations
  Ships operating independently or in task groups
  Simultaneous threats in all warfare areas

- **Difficult Backgrounds for Sensing**

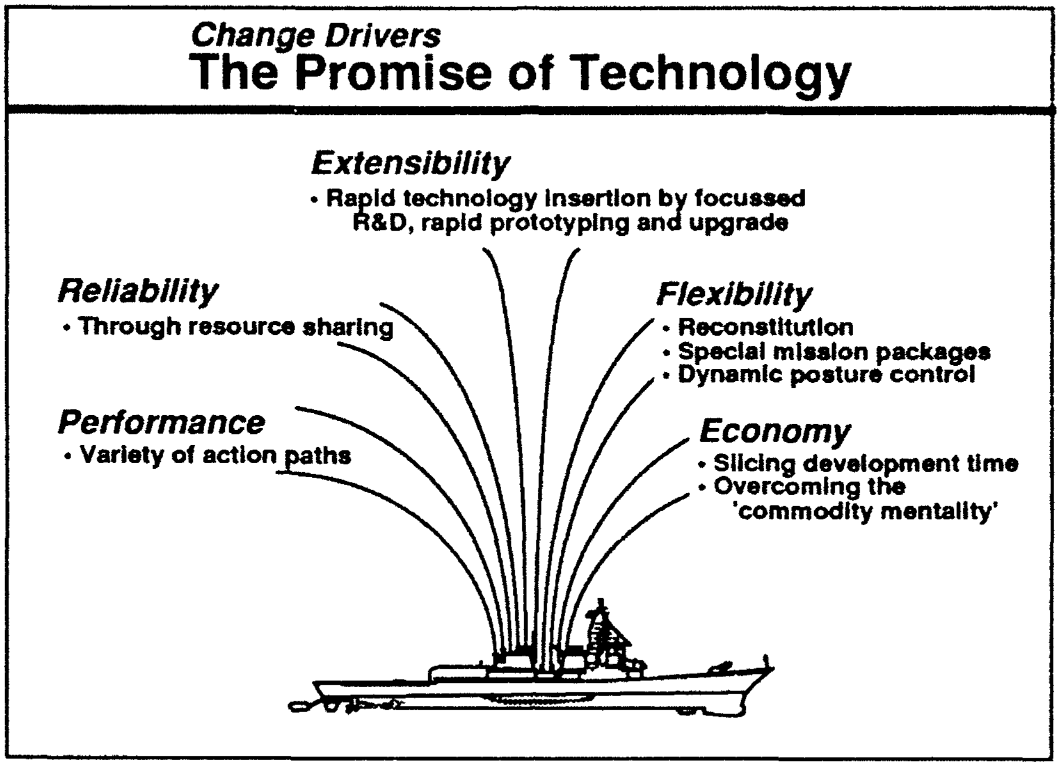
  Heavy land clutter
  Shallow water & cluttered offshore environments
  Heavy commercial traffic -- Air and Sea

OPERATIONAL ENVIRONMENT

This figure shows the expected sequence of roles and aims for naval operations in future regional conflict situations. The cycle begins with stability operations based on the use of forward deployed naval forces to signal U.S. interest and deter the outbreak of military conflict, if possible. A buildup phase would occur as the precursor to forward deployment of air and ground combat elements.

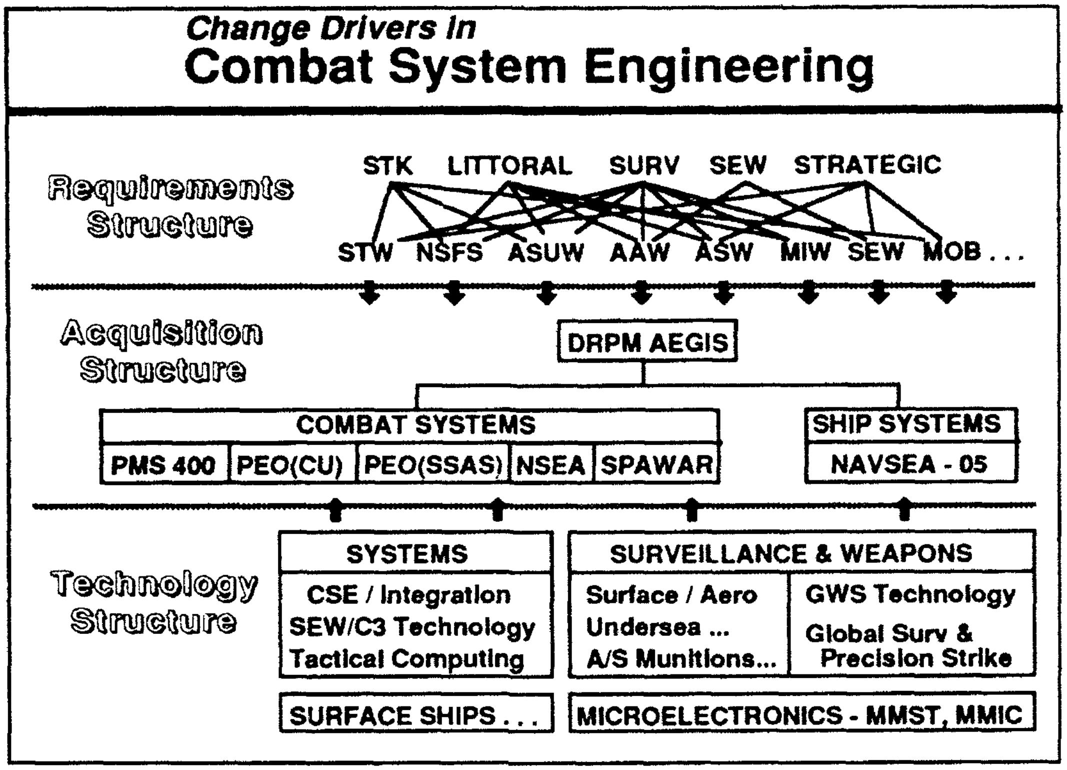
Threat rollback operations will then be conducted to suppress enemy offensive elements, secure U.S./allied lines of communication, and position forces for a power projection phase. This phase will be decisive, but follow-up action will occur, probably at a reduced tempo of operations, to eliminate residual elements of enemy forces and secure key U.S. objectives. Even after heavy combat operations end, a level of naval presence would likely be maintained for an extended period, supporting efforts to restore civil authority and extract U.S./allied forces.

Cruisers and destroyers of the 2010 to 2030 era will operate offensively and defensively as integral elements of a wide range of force packages, and also as independently operating units. Multipurpose surface combatant task groups will become more important as Navy force packages, along with carrier battle groups and amphibious readv groups. They will be capable of operating worldwide and as an element of large or small naval, joint, and combined forces. They will also have the capability to deploy promptly and be fully ready for extended operations, including to areas where the availability of support may be limited, uncertain, or nonexistent.



PROMISE OF TECHNOLOGY

Technology, particularly the computer-related technologies, promises to permit significant improvements in combat system capabilities for the future. The areas of improvement shown in this figure also comprise a set of metrics for judging the relative merits of combat system designs.



CHANGE DRIVERS IN COMBAT SYSTEM ENGINEERING

Combat systems typically involve a number of subsystems and elements, independently developed and optimized by a range of supplier activities. In part, this simply reflects the nature of warships—large, complex systems using a wide range of technologies.

It also reflects the bottom-up design approach, which has been dominant in development of naval combat systems since the 1950's. The basic concept is to deal with problem complexity by dividing the component development responsibilities among a loosely coordinated array of program offices. Each program office will then build, test, debug, and finally produce the necessary components. A combat system is then produced by a process of component assembly and integration. The basic architecture could be called federated.

Today's combat systems mirror the bottom-up approach that underlies how we are organized and conduct business. Components may be developed in many different programs, often using distinct hardware, software, protocols, and standards. The components are then procured as commodities and assembled to form a composite combat system. With such a diverse array of components, creating well-integrated combat systems becomes a major effort.

Through the 1970's and 1980's, the AEGIS program helped us to overcome the obstacles posed by a commodity-based acquisition system to produce highly integrated and capable combat systems. Over much of that time, the problem faced was essentially to introduce the concept of combat system architecture and the discipline of its use. We believe that a new emphasis on this concept and the total system engineering approach it entails can pay off in ships that are more affordable and capable.

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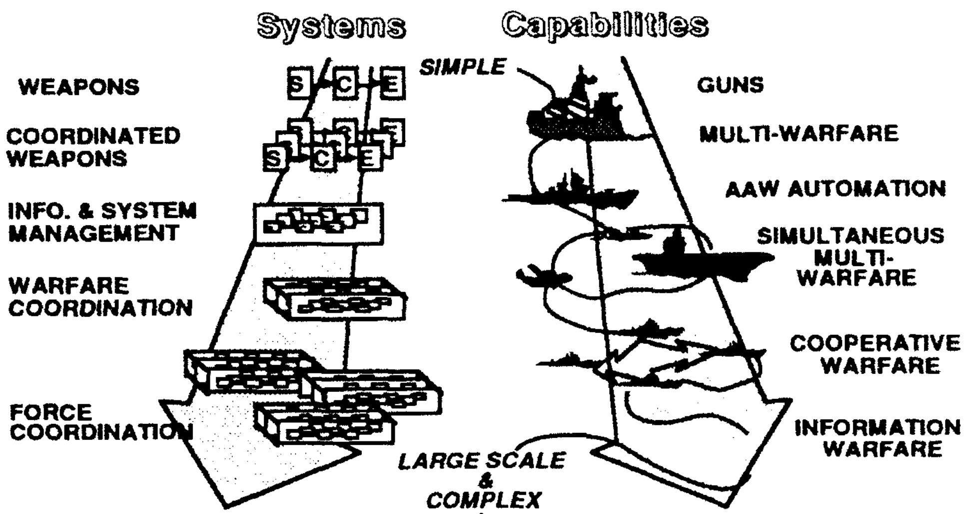
VISION ARCHITECTURE

A key component of the vision is a functional architecture for combat systems designed with the flexibility to support implementation of new naval maritime strategies as they evolve. This architecture involves a horizontal organization of weapon systems, plus vertical layers for individual ship and multiship coordination.

This section gives a brief review of the vision architecture. Subsequent sections present some ideas on how to proceed with development of architectures for advanced surface ship combat systems.

An Evolving Navy

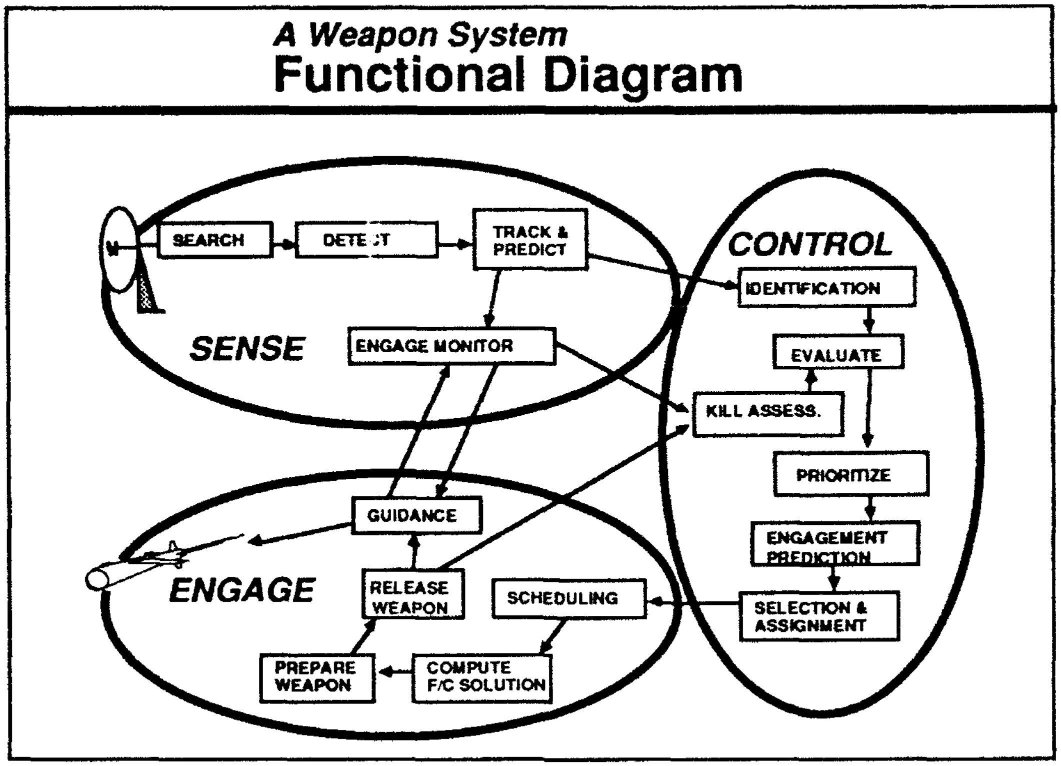


Combat systems are complex composites of plant, people & procedures; they evolve gradually with component changes

AN EVOLVING NAVY

No matter how urgent, the desire for change in combat systems must be reconciled with the reality of a large existing fleet. Today's fleet is both a capital resource of great value and a repository of our experience in building and operating naval forces over many years. Tomorrow's navy must evolve from where we are today.

In addition, due partly to the complexity of combat systems and partly to the stability of naval doctrine and tactics, the processes of change in combat systems are strongly evolutionary and driven by military need more than technology. The processes of change are different at the weapon system level. Technology drives innovation, and entire weapon systems may be replaced when they become obsolete. Successful change demands proper meshing of the two different change processes, and radical change is both risky and rare.

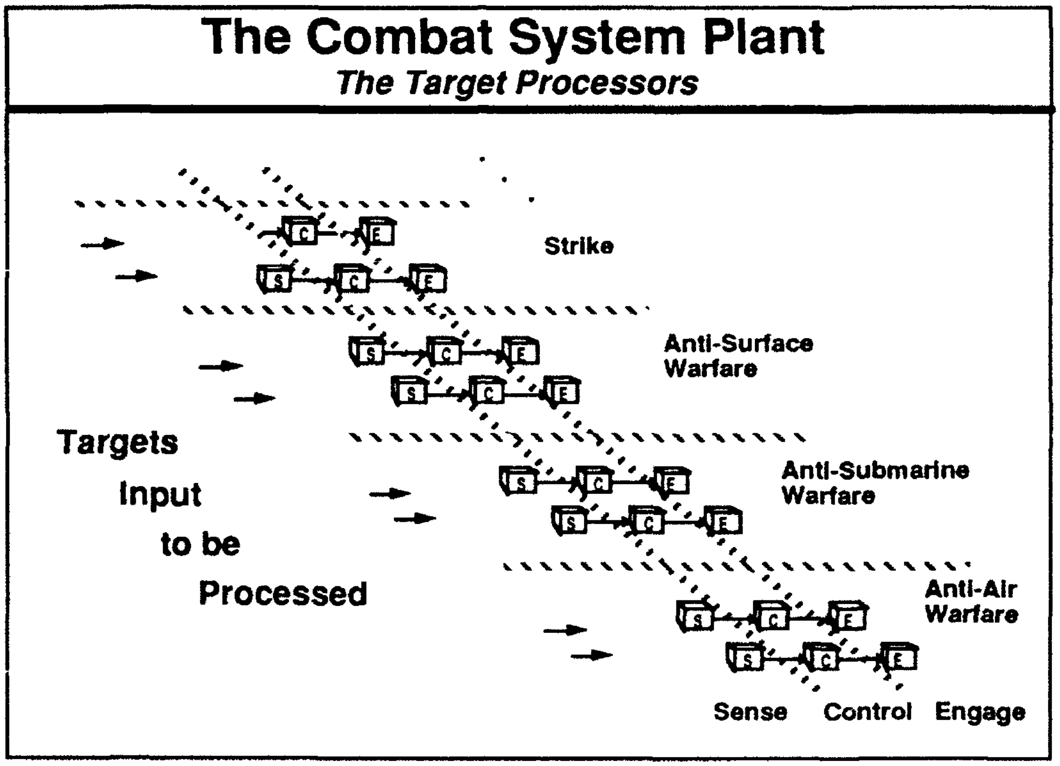


WEAPON SYSTEM FUNCTIONAL DIAGRAM

Within the context of this *evolutionary imperative*, it is clear we are in a time of change. Changing defense needs, technological progress, and prospective changes in acquisition strategy are combining to make this a critical juncture in combat system development.

Accordingly, we chose to begin the combat system vision effort at a very basic level; i.e., the individual weapon system or warfighting path. Every warfighting path or process involves a string of discrete actions or functions, designed and sequenced to achieve a significant combat task. Such strings of discrete actions or functions, termed action paths, are generated by weapon systems. Rigorous definition of action paths can require significant technical effort and is a fundamental task in weapon design. Here, the intent is only to group functions into sense, control, and engage modules, as a useful convention for representing action paths. These modules are viewed as functional rather than physical entities. For example, the sensing function in an anti-surface warfare action path could be supported by an acoustic sensor intended primarily for detection and tracking of submarines.

The illustration is taken from antiair warfare (AAW), but sense, control, and engage sequences are present in all weapon systems; i.e., all engagements require sensing to gather target and environmental information, controlling to prioritize and assign weapons to targets, and engaging to deliver energy against the target.

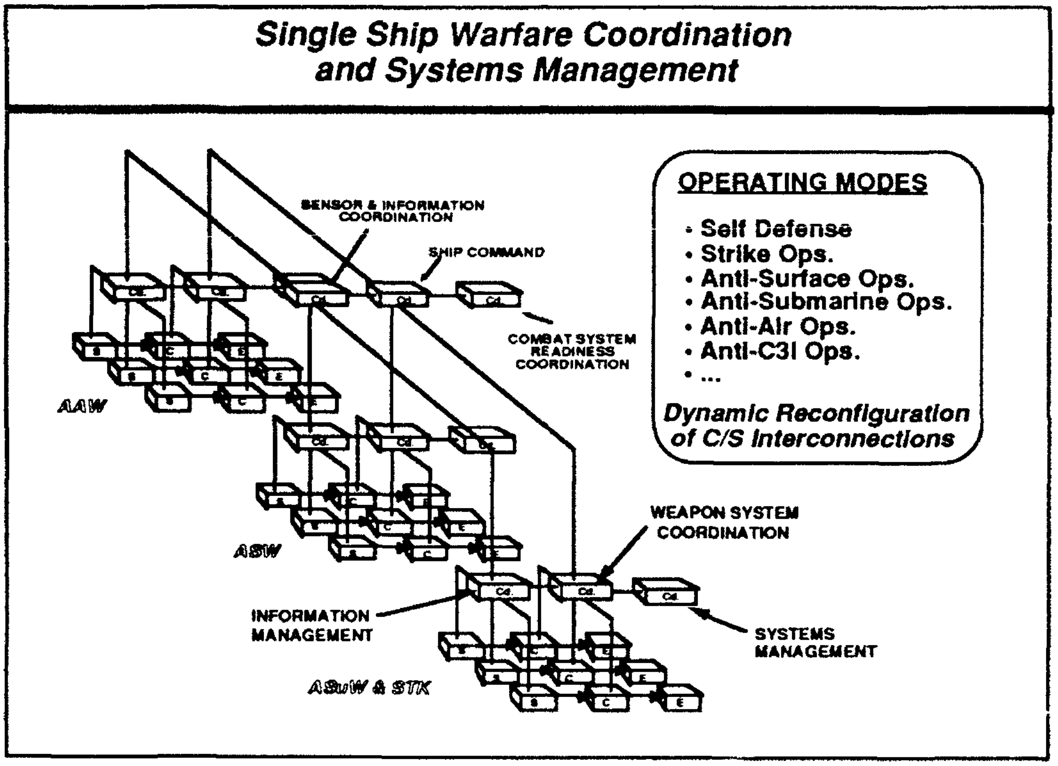


COMBAT SYSTEM PLANT

A combat system may be viewed as a plant for the processing of targets, in which value is created by execution of warfighting processes under orders. In short, combat systems that can process targets better than those of the enemy win battles.

Since many different action paths are employed, each critical to some aspect of mission performance, combat systems are designed around the mix of action paths that must be produced. Setup, coordination, and control of these action paths is the defining purpose of the combat system. In essence, combat systems that can process targets better than those of the enemy win wars. In the figure, action paths are arranged by warfare mission areas to suggest the conventional approach to organization for battle management and control. However, action paths can be grouped in other ways with little effect on the architectural framework.

With these conventions for describing and arranging action paths, we can go on to consider coordination of multiple weapon systems, warfare mission areas, and finally multiple ships and/or aircraft. The result is said to be a functional rather than a physical or implementation architecture. Functional architectures merely define processes, while implementation architectures define the structure by which processes are controlled and executed. In this data and control flows, computer programs, interconnections, and resource flows are important. Physical architectures are yet another type, concerning mainly the spatial arrangements and mechanical structures of plants and equipment.



COORDINATION AND SYSTEMS MANAGEMENT

This figure shows the combat system as a network of modules arranged in three layers. The bottom layer consists of warfighting paths. The middle and top layers consist of coordination functions. The former provides separate coordination and control in each warfare mission area so that simultaneous multiwarfare operations can be conducted. The top layer is the unit command level, where tactical objectives are established and resources are assigned to coordinate multi-warfare operations. Information and Readiness Coordination functions are provided in this layer to ensure that Command is not overburdened with the details of external communications, tactical information handling, and resource monitoring.

These coordination layers introduce two vertical path types to the architectural framework. The paths connecting the commanding officer (CO) and tactical action officer (TAO) to individual action paths are called command paths and form the command hierarchy of the combat system. Their role is to project command authority and to protect its integrity throughout the combat system. As shown in the figure, the command paths support both readiness and warfighting coordination. The paths that connect the information coordination functions to sensing resources (including communications) are called information paths and form the interconnecting structure for combat system data flows.

Overall, three fundamentally different control path types are present: action paths, command paths, and information paths. This creates a potential for information and resource sharing, which is essential to the integration and affordability properties of the combat system. A subsequent vugraph will highlight the importance of dynamic reconfiguration to create operating modes tailored to particular operating tasks and roles.

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IMPLICATIONS FOR ACQUISITION

The development organization guides the allocation of resources for translating requirements into an optimal set of products. In a sense, the key is to develop the information needed by producers to build the combat system.

Within the vision architecture, three types of integrating structure occur. In this section, three types are outlined and then are considered how they may be used to partition the problems of combat system design and engineering into three parts. This suggests a possible framework for acquisition.

System Engineering Principles

System Partitioning

Large-scale systems should be partitioned in such a way that the major components or subsystems which result are loosely coupled . . . .

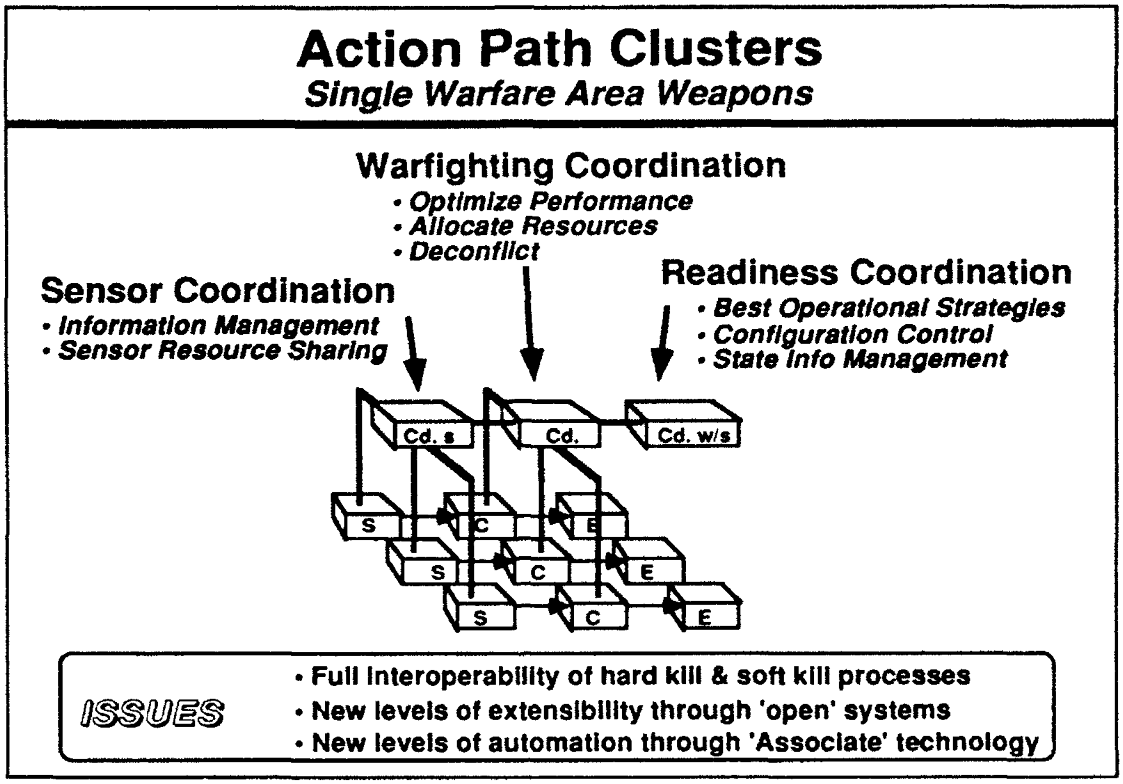
Development Organization

Development activities should then be formed around these loosely coupled components or subsystems . . . .

SYSTEM ENGINEERING PRINCIPLES

These principles highlight the basic importance of system partitioning for management, as well as engineering design purposes. This section considers a partitioning of the overall combat system into three major subsystems. The first is a backbone control structure, employed by the command team to set up and coordinate the clusters of action paths that engage different categories of targets. The second provides for integrated control of multiple action paths in a single warfare mission area; e.g., as in the AEGIS Weapon System. A third n.ajor subsystem provides for control of external information flows.

However the combat system is partitioned, the structure of the acquisition or system engineering management organization should correspond. Any serious misalignment of product and producer structures tends to be reflected in poor efficiency and suboptimized systems.



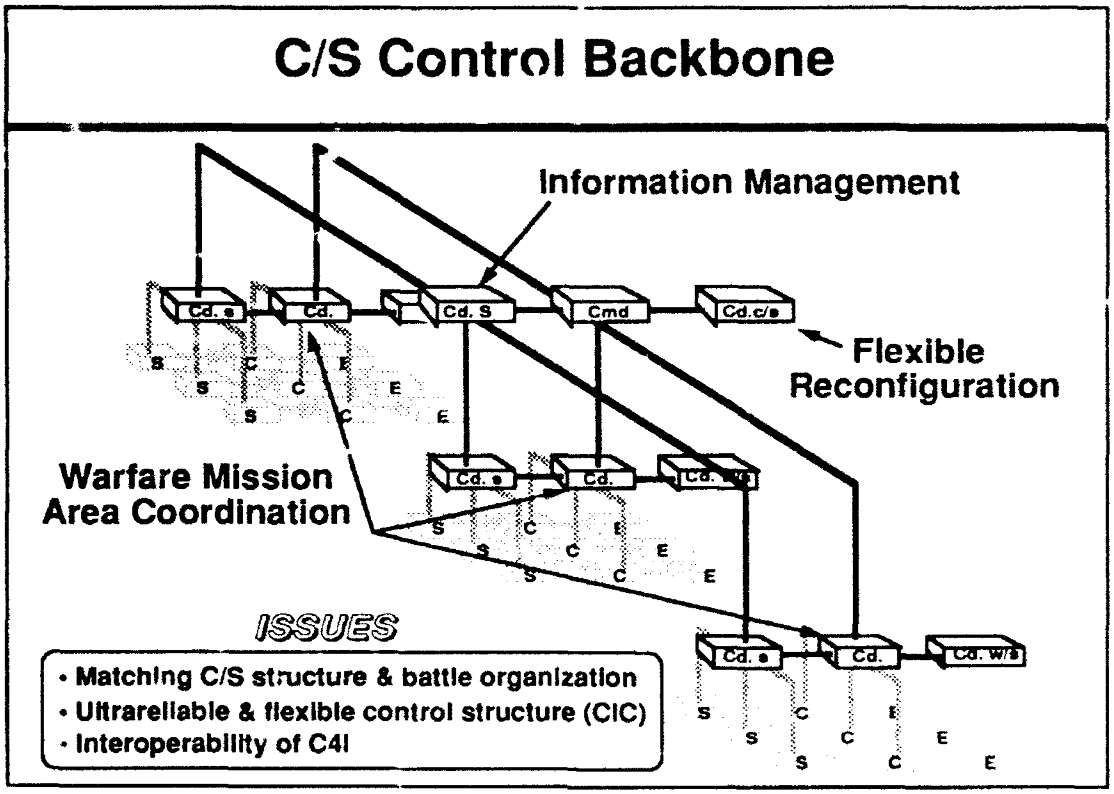
ACTION PATH CLUSTERS

The first category provides for integrated control of multiple action paths within a single warfare mission area. Action path clusters accomplish local control functions, including the coordination and direct control of individual action paths for target processing. The primary concern at this level is quality of the warfighting paths.

The AEGIS Weapon System, for example, provides for shared use of resources across multiple simultaneous engagements. Separate control paths are provided for air intercept operations and self-defense assets (e.g., electronic countermeasures (ECMs) and minor caliber gun systems).

Today, advanced antiair self-defense systems are being developed that will integrate dissimilar action paths. Key technical problems include multisensor integration and the integration of hardkill elements with softkill elements.

Combat systems are actually more complex than shown in the vugraph, because each warfare mission area tends to contain multiple clusters of coordinated action paths. The AAW mission area, for example, may contain a cluster of area defense surface-to-air missile action paths, a cluster of air intercept action paths, and a cluster of short-range (self-defense) action paths including missiles, gunfire, and ECMs.

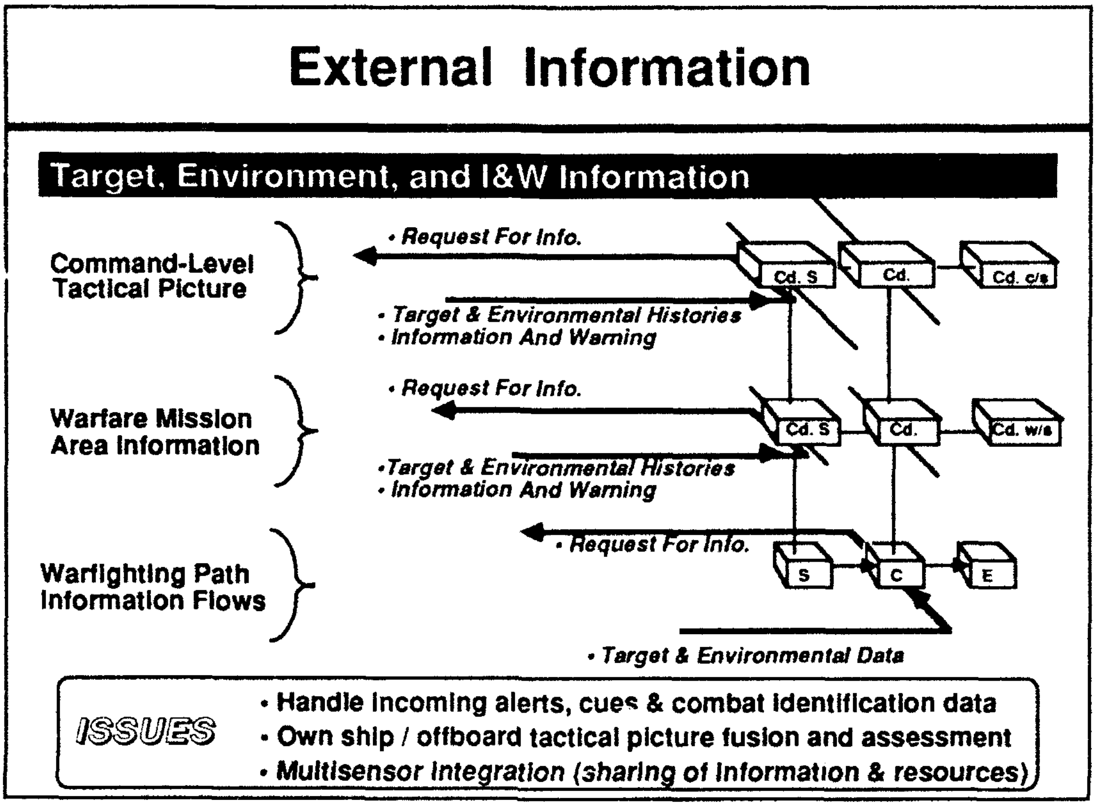


COMBAT SYSTEM CONTROL BACKBONE

The second type of integrating structure, backbone control, matches overall combat system structure to the battle organization. This level of control enables the command team to provide loading and balance controls for the main operating tasks of the combat system. Space and time, information and processing, targets and ordnance, energy, and manpower are the resources to be considered.

The primary functions of backbone control are those of supervisory rather than direct control of target processing. As a backup or casualty mode, however, it is believed that command team workstations should be capable of exercising direct control of warfighting paths.

It is noted that the issues listed here, and on the next few pages as well, are not architecture issues but broad engineering and technology issues. Only the partitioning of issues among backbone system types is attributable to the architectural framework.

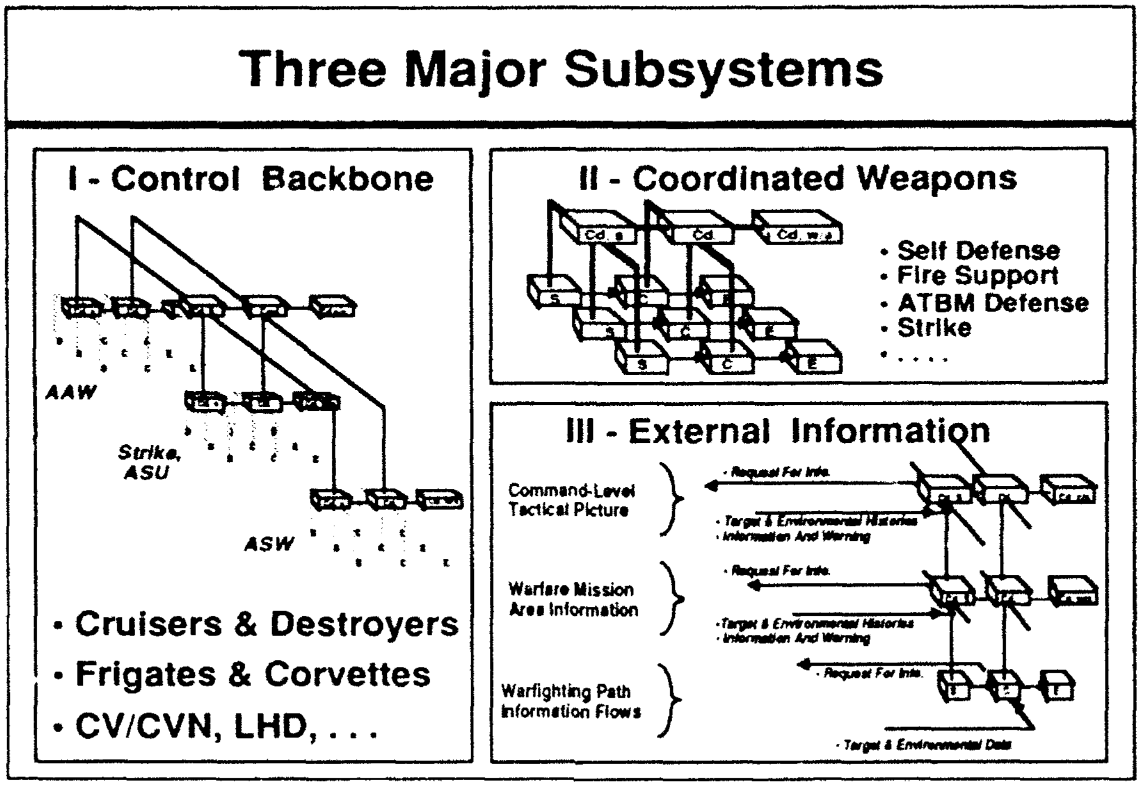


EXTERNAL INFORMATION

The third category of integrating structure provides for control of external information. This includes external communications, fusion of ownship with offboard information, and coordination of information flows throughout the combat system. However, it does not include direct control of information flows essential to target processing, including interior communications.

The figure indicates that information from external sensors and sources is used at three different levels within the combat system. At the lowest level, external or nonorganic sensors can act as virtual sensors that furnish the target and environmental data needed by the control and engage functions to complete the warfighting path for target prosecution. The weapon system control function can also request information or services from these external sources as it would with its own sensors.

Above this level, external information is used to support sensor coordination functions such as planning, forming a tactical picture, and assessing ownship's tactical posture. The same types of information (indications and warning, target tracking data, and environmental data) are supplied to warfare mission area coordinators (warfare area level) and the CO/TAO positions (unit level). While both coordination levels use the same types of information, the content will differ in terms of the scope and level of detail provided.



THREE MAJOR SUBSYSTEMS

Advanced implementation architectures are needed in each of these areas, and in each case major programs exist, or are being created, to work problems of the highest importance to the U.S. Navy's future.

- Such efforts as the Destroyer Variant Study, the 21st Century Destroyer Study, and the High-Performance Distributed Processing (HIPER-D) project [a joint venture by the Defense Advanced Research Projects Agency (DARPA) and PMS-400] promise to open the way to advanced backbone control systems.

- The Global Surveillance and Precision Strike initiative, working through the TOMAHAWK Weapon System, opens a way to advanced architectures for management of external information for new construction cruisers and destroyers.

- The addition of the Evolved SEASPARROW Missile System to new construction DDG 51 units, together with the newly created Ship Self-Defense initiative, opens a way to advanced architectures for action path clusters.

Though it is important to involve a wide range of contributors in each area, to arrive at consistent and compatible subsystem architectures, it appears there is a natural choice for the leadership role in each area.

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TECHNOLOGY

Continuing technological progress holds promise for all of the major subsystems identified above—control backbone, external information, and action path clusters. This section considers a concept for future control backbone systems. The concept given is illustrative rather than discrete.

In recent years, it has become increasingly apparent that distributed computing technology will have a major influence on the character of future combat systems. A variety of concepts for distributed computing in combat systems already exists. In most, the computing plant is viewed as a modular network of many processors. All computer programs are able to run independently in any processor. The system architecture is intended to be enduring and flexible enough to permit

- Application to a range of platform types
- Upgrade through addition of new sensors and weapons
- Insertion of new-generation computing technology as it evolves

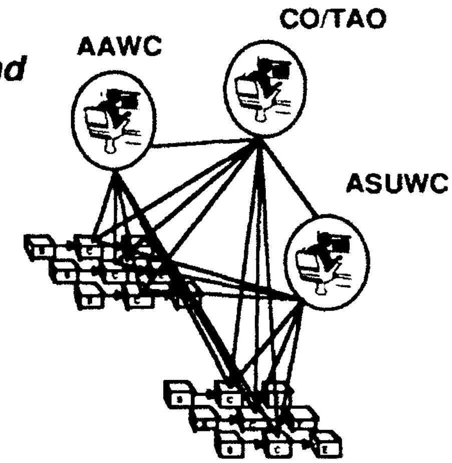
An extension of this basic system concept is outlined to include parallel and redundant control structures. This permits control architectures that combine high reliability with high configuration flexibility. Computerized workstations, interconnection networks, and multiplex control structures are thus the key technologies that will permit realization of dramatically new capabilities in future combat systems.

Flexible Interconnection

EXAMPLE: Control Backbone - Warfighting Coordination

<u>**Multiplex Control allows for:**</u>

- ***Configure for Effective Command***
  Match system / Battle Organization to warfighting tasks at hand
  Reallocate W/S Resources for Failure / Battle Damage
- ***New Levels of Automation***
  Pilot's Associate Technology for Information management
- ***Ease of Upgrade***

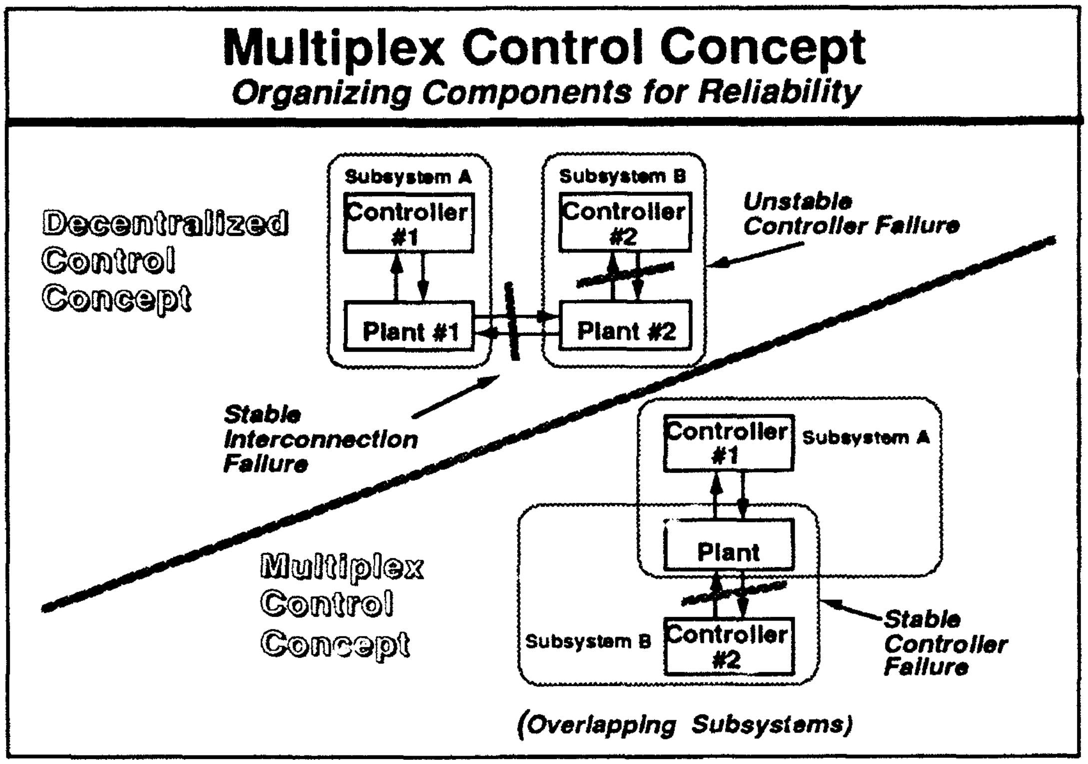


FLEXIBLE INTERCONNECTION

It is envisioned that in future combat systems, the command team (CO, TAO, combat system coordinator, tactical information coordinator, and the warfare mission area coordinators) will one day control all essential warfighting tasks without the aid of subordinate control personnel. They will also attain new levels of life-cycle effectiveness, with overall system reliability, flexibility, and extensibility treated as matters of great importance.

Although such a combat system may not be fully realized in this decade, or even the next, a partial capability permitting the command team to fight the ship as a degraded mode of operation is quite conceivable. This can be achieved using technologies explored in the Pilot's Associate and similar programs of recent years to begin a process of absorbing functions now assigned to other workstations.

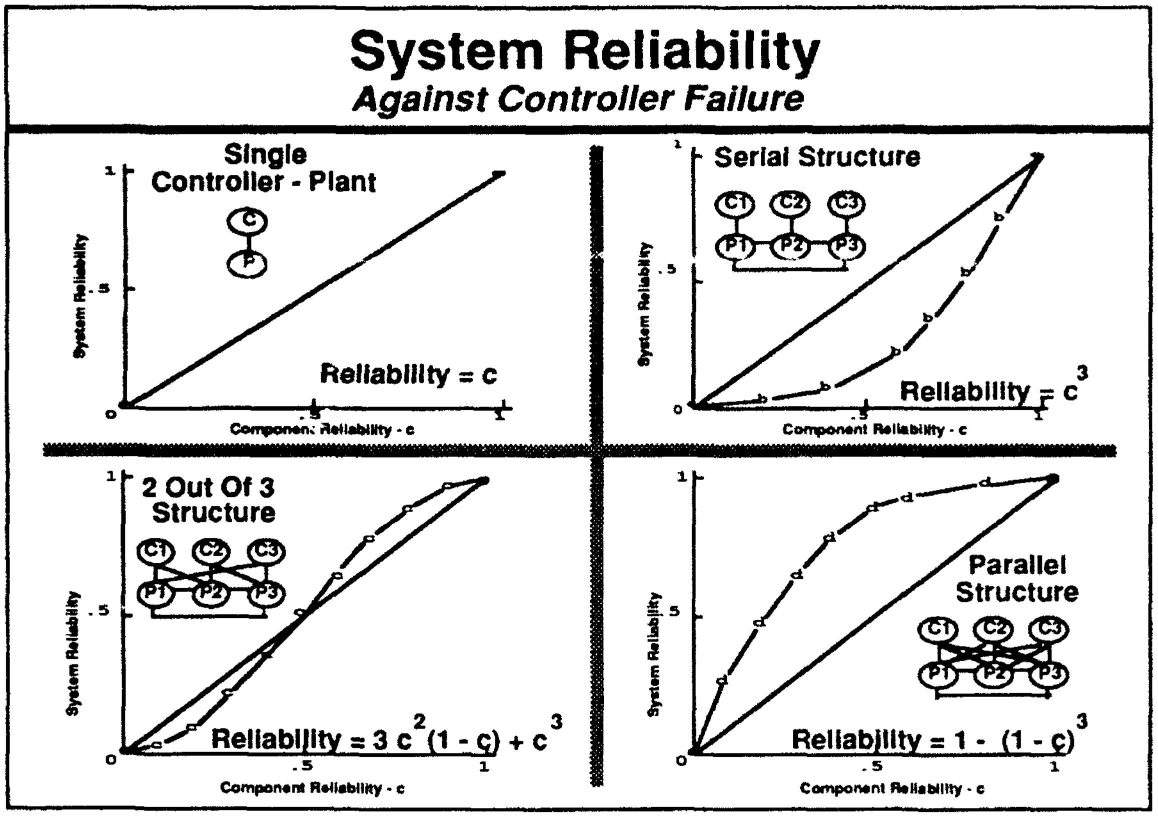
At first, this would provide only an automated backup to the subordinate controller workstations. As the technology matures, the backup configuration can evolve into a new watch condition with reduced manning for use in peacetime cruising conditions. Added manning would bring higher states of readiness to Condition III and then Condition I levels. Eventually, the functionality of subordinate controllers will migrate completely to the command team workstations. The combat system would then be fully automated at lower levels of control. Reducing the size of command teams is possible in the long run, but a radical change of battle organization, with results that can only be speculated on at present, will likely be necessary as a precondition.



MULTIPLEX CONTROL CONCEPT

One possible application of advanced control techniques to combat systems is shown here. Recent decades have seen a trend to decentralized control structures (top left) that are robust against interconnection failures (bottom left). However, they depend on a static interconnection structure that leaves them vulnerable to controller failures (top right). From the reliability point of view, decentralized control schemes are series connections of controllers, yielding no redundancy in control capability. The term *decentralized* refers in this context to the control information pattern. It signifies that within a given layer of the control structure, different controllers have access to different (specialized) information. For example, an AAW area coordinator would not have access to strike information.

A key principle in the engineering of complex systems is that unreliability of components should be overcome, not by making the components more reliable, but by organizing them in such a way that the reliability of the whole is greater than the reliability of its parts. This principle was initially formulated in the design of reliable computers. Its application to the design of control structures has been achieved only in recent years. Parallel redundancy can be achieved with respect to control capability through the use of multiple control units, with two or more controllers assigned to the plant or some part of the plant. The generic case is shown here (bottom right). When one controller fails, the other is capable of carrying on the plant. The result is the concept of a multiplex control system, in which information can be shared among different controllers. This corresponds to the creation of overlapping subsystems.

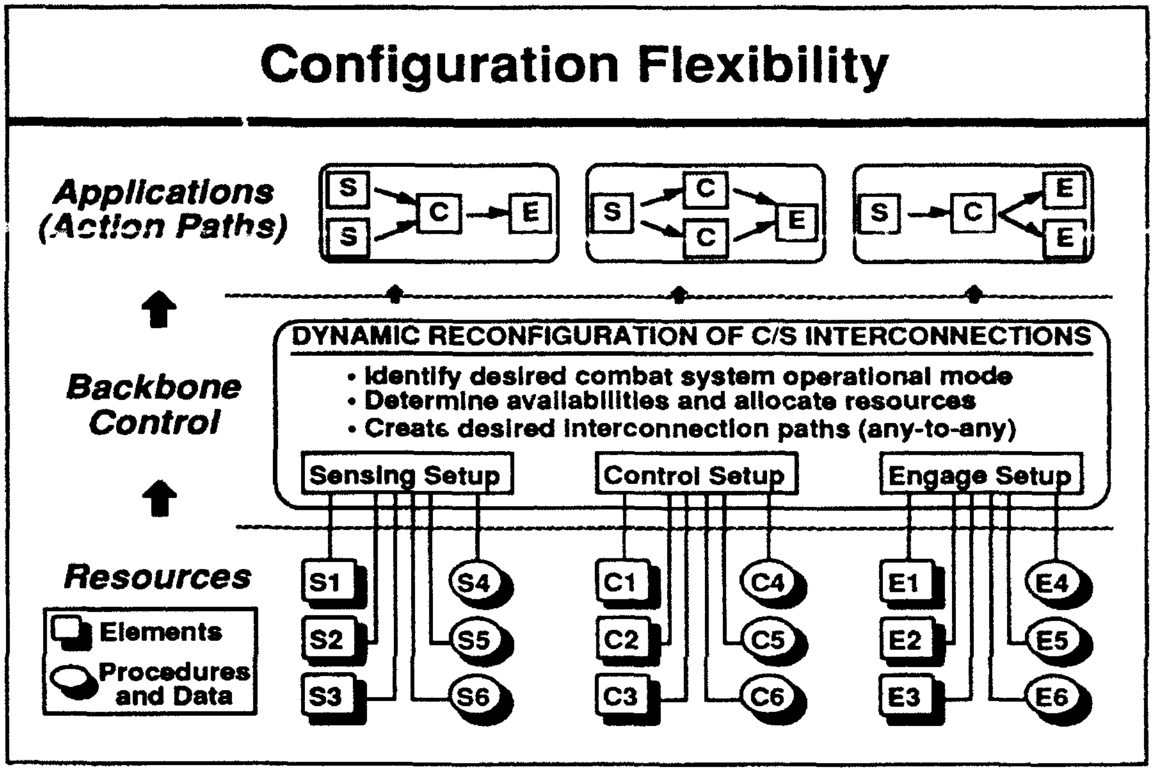


SYSTEM RELIABILITY

Consider four control structures with the reliability functions shown in the four quadrants of this vugraph. It is assumed all controllers have the same reliability (c). The single component structure (top left) is the simplest case. The series structure (top right) is the least reliable with regard to control failures, but it is also the most reliable under perturbations in the plant interconnections; i.e., under plant failures. The parallel structure (bottom right) is the most reliable with regard to control failures. It is also the least economical, since three controllers serve a single plant.

The S-shaped curve for the two-out-of-three structure (bottom left) indicates highly reliable control systems can be achieved with relative economy using parallel or redundant controllers. If controller reliability (c) is greater than 0.5, system reliability for this case falls above the diagonal line f(c) = c, and the overall structure is therefore more reliable than a single controller. Thus, a combination of decentralized and multiple controllers may be used to account for both interconnection and plant failures. (This gives rise to a problem in optimal redundancy allocation.)

Reliability of control is a key concern in the design of large scale and complex systems. When a single-purpose controller is used and redundancy is provided at component level, a failed component often cannot be repaired or replaced during operation. If redundancy is achieved using multiple controllers in a parallel arrangement, a failed controller can be disconnected, tested, and repaired or replaced without interrupting system operation.

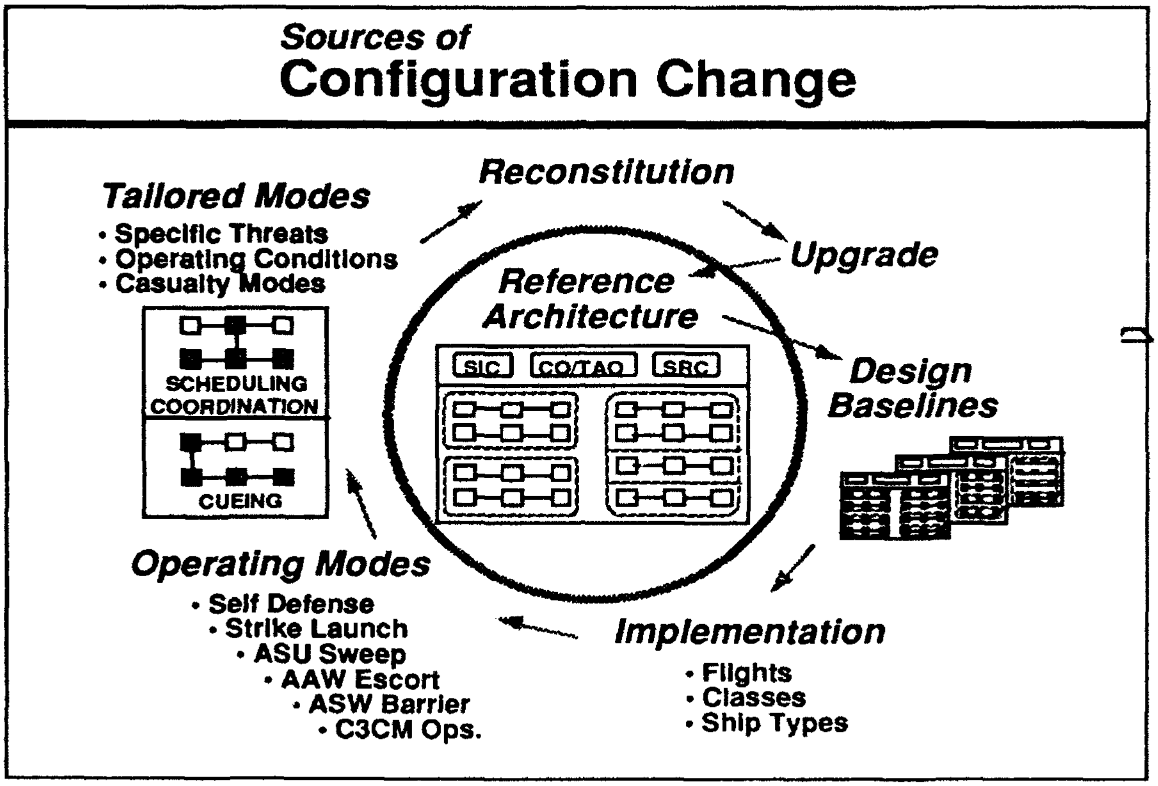


CONFIGURATION FLEXIBILITY

This vugraph illustrates how the dynamic interconnection structures permitted by the multiplex control concept can be applied to backbone control in combat systems. It is envisioned that sensing, controlling, and engaging subsystems would be designed to permit formation of action paths by automatic linking of components (any-to-any) to constitute effective warfighting paths. A combat system will thus be able to continuously redefine information and control flows by altering its interconnection structure.

With this approach, combat systems can be designed for high dynamic reliability; i.e., they can be designed to ensure stability of the controlled system under a variety of controller faults that occur with given probability.

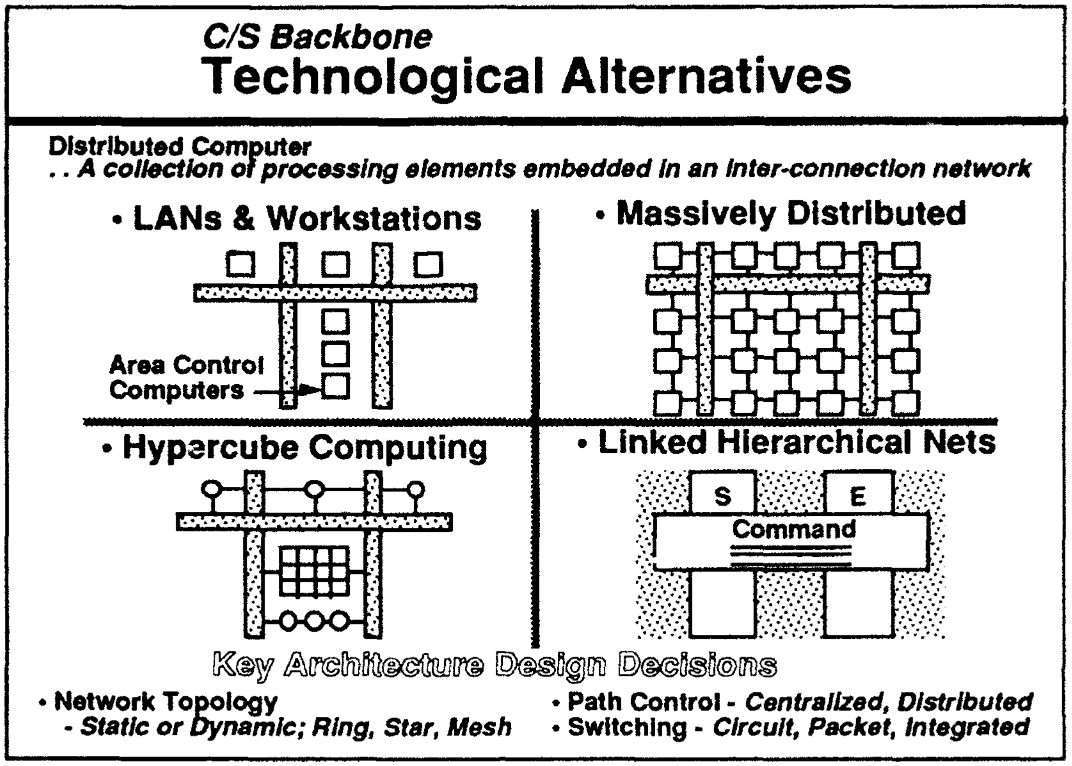
Development of ultrareliable distributed control systems promises a significant evolution in combat systems. Such change demands parallel development of battle organization, equipment, and system structure. Development of a new structure should begin even before the new equipment is built, using surrogates where necessary. This may involve experiments with new organizational forms, doctrine, and tactics within a pilot combat system. Using such a comprehensive approach, development of new doctrine, tactics, and operating procedures will not lag new technology by many years but will evolve interactively with the new equipment. The full potential of the new concept can thus be realized much earlier.



SOURCES OF CONFIGURATION CHANGE

There is a hidden assumption underlying the way we currently design and build combat systems—that information and control flows are relatively static. We expect data in these flow paths to change quite rapidly as the tactical situation changes, ordnance is expended, new orders are received, and so on. But we do not expect or provide for continuously redefining the way system tasks are viewed. This figure indicates that configuration changes may be necessary for a variety of reasons. Reconstitution or upgrade, platform applications, and evolving design baselines cause changes that can be made slowly, over a long timeline. Shifting operational modes and threats, battle damage, equipment failures, and the desire to tailor operating modes to specific operating environments may demand a capability for dynamic management of interconnection structures.

The design of sensing, control, and engagement components for any-to-any interconnection can support a virtually unlimited repertory of action paths, with flexibility to create new operating modes tailored to specific operating tasks and roles. The assignment of resources to a given action path need not be a fixed characteristic of the design. Resource assignments may be dynamic, varying with assigned missions and tasks at any point in time. Effective use of a large repertory enhances a commander's ability to dictate the terms of action and achieve the advantages of surprise in tactical operations. The existence of multiple data and control paths through the combat system also creates opportunities for increased survivability and growth potential compared to fixed-path designs. Thus, future combat systems should be able to continuously redefine information and control flows by altering interconnection structures.

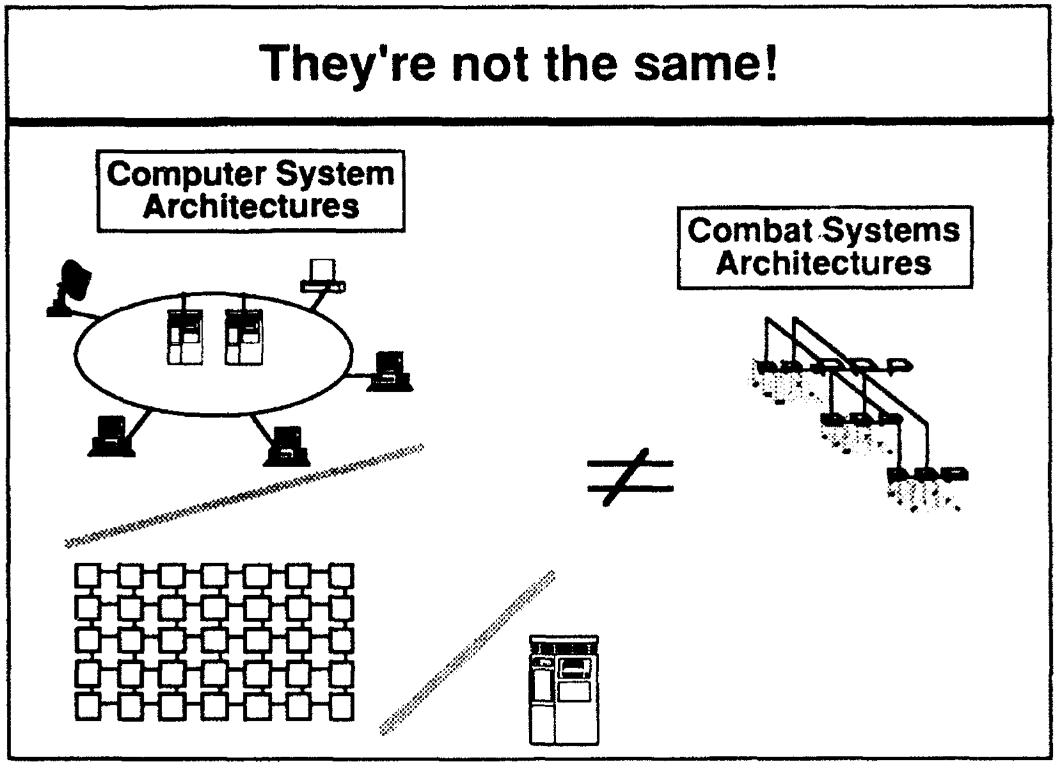


COMBAT SYSTEM BACKBONE TECHNOLOGICAL ALTERNATIVES

Computerized workstations, interconnection networks, and multiplex control structures are among the key technologies that will permit realization of dramatically new capabilities in future combat systems. This figure shows a variety of embedded computing configurations that might be used to implement control backbone systems. Each quadrant involves a different mix of spatial distribution, information pattern, interconnection structure, and task partitioning (e.g., mission vs. function or object) characteristics. Dynamic reliability, timing, modularity, and automation are issues that call for experimental work.

The top left quadrant shows dedicated computers for warfare mission area subsystems, as well as information coordination, command support, and readiness coordination positions. The computers are interconnected and goal coordination is provided by a designated unit, such as the command support computer. This corresponds to an hierarchical form of distributed computing and matches the control structure prevalent in existing surface combatants. The top right quadrant shows a massively distributed structure akin to the DARPA HIPER-D approach.

The bottom left quadrant shows a central parallel processing system with smart workstations. Although spatially concentrated, individual processors in this configuration could be allocated in a flexible way to specific processing tasks. The bottom right quadrant shows a functional structure for embedded computing in combat systems. Action paths and coordination functions are assigned to the command subsystem. Connections between sensing and engaging elements are assigned to sensing and control subsystems, respectively. Each subsystem is considered to contain a separate interconnection network. However, the networks are linked at important interfaces.



THEY'RE NOT THE SAME!

This report espouses architecture as an aid to development of future combat systems. The idea is to relate an engineering task to the purpose of an end user; i.e., warfighting at sea. The tendency to view combat system and computer system architectures as equivalent constructs should be resisted. Though combat system operations are highly information intensive, it is quite possible to place an excellent computer system in a very bad combat system.

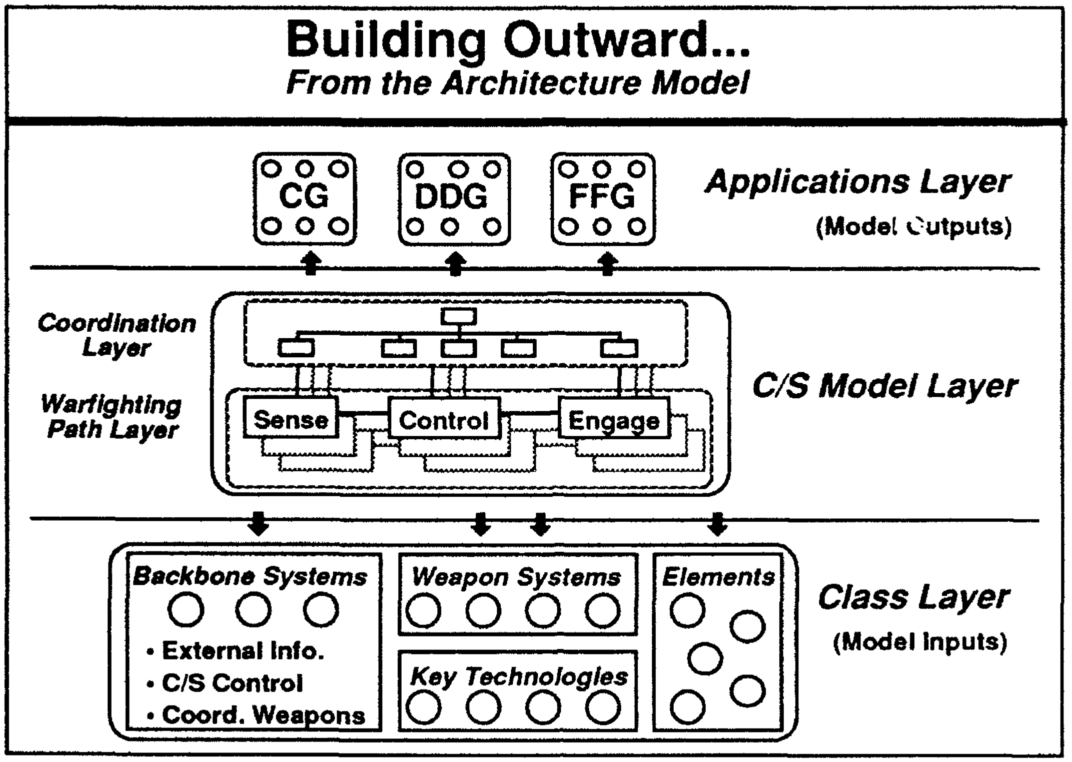
Outline

- 2030 Vision Effort
- Change Drivers
- Vision Architecture
- Implications for Acquisition
- Technology
- How Might We Proceed ?
- Summary of Key Points

HOW MIGHT WE PROCEED?

A balanced approach to combat system development demands careful consideration of battle organization, equipment, and control structures. This involves interactions between component and overall system architectures that call for changes to existing acquisition paradigms. Ways of progressing toward the new acquisition framework envisioned are considered in this section.

The root concern is the capacity of the U.S. Navy to build sustainable warfighting advantages from basic U.S. military and industrial strengths. However the world situation evolves, the U.S. Navy must be armed and equipped with affordable, usable, and effective combat systems, sufficient to execute an appropriate concept of operations against a capable and determined adversary.



BUILDING OUTWARD

This figure shows how the vision architecture and the partitioning considered here fit into an acquisition framework for future surface combatants. In essence, the vision architecture constitutes a reference model (center) for the combat systems to be produced. Particular combat systems (top) are realized by selection and assembly of appropriate systems or designs from the tiers of the supply chain (bottom). The bottom layer of the illustration corresponds to the input side, and the top layer to the output side of this model.

The three major subsystems identified in a previous vugraph (here called backbone systems) create a new tier in the supply chain for combat systems. The resulting chain consists of four tiers, each containing a set of class reference models and, within each class, a set of particular systems or designs. A set of policy goals can be identified for each of the four tiers as follows.

- Backbone Tier: Buy for the long haul, with emphasis on open architectures, to form stable product lines for each major subsystem type.
- Weapon System Tier: Move toward resource sharing across weapon systems (e.g., sensor integration, multipurpose controllers).
- Elements Tier: Design elements and components for reusability.
- Enabling Technologies: The first goal should be to exploit emerging technology to form the tiers described above. New technology can then be deployed quickly through evolutionary acquisition.

C/S Architecture
Coordination Matrix

← Major Subsystems →

WARFARE AREA ↓

	External Information	Control Backbone	Action Path Clusters
STRIKE			
AAW			
ASW			
ASUW			
CCC			

COORDINATION MATRIX

Mechanisms are also needed to coordinate the development and application of requirements, reference models (architectures), and component systems or designs across the tiers of the supply chain. There may be many ways to achieve the necessary coordination, including the following:

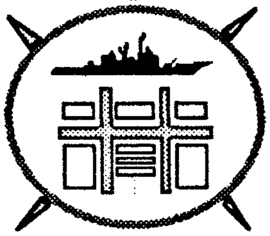
- Consensus standards and top-level requirements
- Organization and development planning guidance
- Strategies for system-level oversight and control
- Policy coordination at service and DoD levels

The coordination matrix shown in the figure above indicates one way in which requirements, standards, and strategies might be coordinated across warfare mission areas to aid formation of the backbone systems tier. It should be recognized that information is the primary contribution of system engineering activities to acquisition. Value is created by transferring information to builders and suppliers that defines a process for implementing combat system features and by developing information on critical features, risks, and benefits of such features so that practical and affordable development programs can be defined. Many development problems occur when essential information is not obtained and made available to those who need it. What is needed is a new framework for acquisition, designed to enable identification of key information in a systematic way. This means systematic identification and analysis of development mission and functions to be performed, who is to perform them, information and supporting data needed to perform those functions, and processes needed to most usefully structure the information. Use of architectures and related standards and efforts to capture and formalize design practices are important enabling steps to allow the degree of information sharing necessary to practice modern system engineering methods in a large U.S. Navy/industry team.

Prototyping/Testbed Activity

Explore and evaluate C/S integration techniques via build-and-test paradigm

Parallel exploration of:
- **Evolving user needs**
- **Emerging technologies**



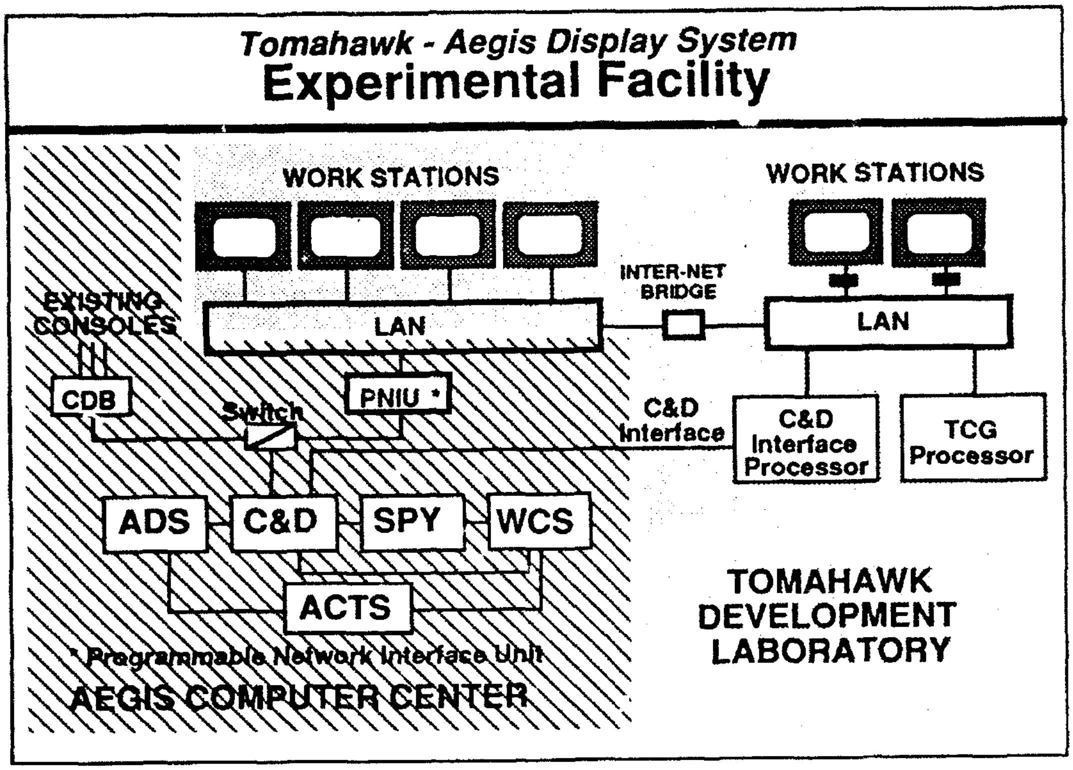
Open program creating a culture of cooperation via:
- **Joint industry/lab ventures**
- **Multi-program cooperation**
- **Builder-user interaction**

Synthetic environment for:
- **C/S design processes**
- **Reusable components**
- **Realistic testing**

PROTOTYPING/TESTBED ACTIVITY

Prototyping is important to refine and validate the architecture model and to determine system requirements through user involvement in an experimental mode. Testing in the TOMAHAWK-AEGIS Display System facility, located at Dahlgren, has already demonstrated the utility of an experimental approach to evolution of advanced combat system architectures. It is envisioned that emergent computing, networking, and control technologies can be exploited in a prototyping effort structured as follows:

- Phase 0: Identify prototyping requirements and applicable standards in a startup phase. Workshops would be held to establish prototyping goals and methods.
- Phase 1: Identify candidate technologies and devices. Industry participation is essential in this phase to define strategies for rapid militarization of commercial technologies.
- Phase 2: Conduct tactical and technical experiments to explore, develop, and refine alternative system concepts. Much useful work can be done with existing facilities. If one begins by designing a set of useful experiments, coordination of multiple facilities (even at different sites) may be possible. A synthetic environment for rapid design, development, and interactive evaluation of reusable combat system components would be generated in this phase.
- Phase 3: Evaluate a prototype combat system at sea.

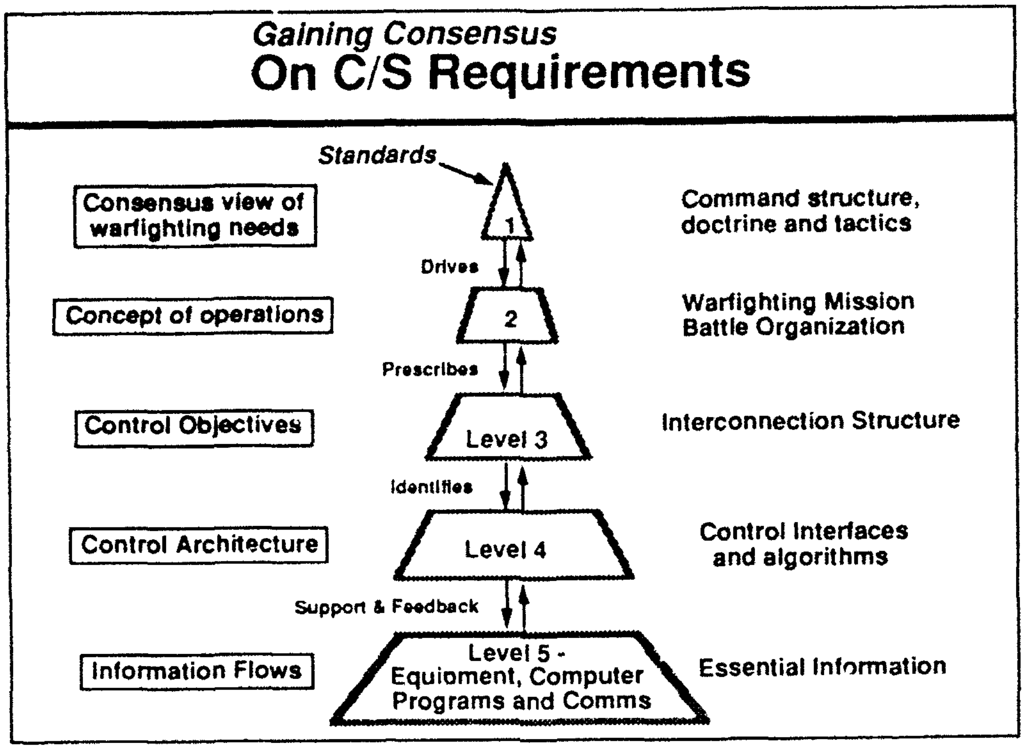


EXPERIMENTAL FACILITY

Experiments were conducted at NSWCDD using existing TOMAHAWK and AEGIS facilities. On the former side, a precursor to the Advanced TOMAHAWK Weapon Control System was implemented in the laboratory. On the latter side, a Programmable Network Interface Unit (PNIU) was installed on the central data buffer (CDB) interface with a switch to permit operation with either the CDB or the PNIU.

Local area networks (LANs), workstations, and computer programs from commercial sources were installed in both laboratories. A bridge was implemented between the two LANs to permit interoperability experiments. Any workstation on either network could be assigned to AEGIS or TOMAHAWK modes. Experiments were conducted to examine the feasibility of replacing the console group by a LAN/workstation setup with considerable local processing and storage capability.

From an architectural viewpoint, the results of these experiments were very significant. The test equipment was introduced at key points in the combat system, the human-machine interfaces, where the functionality and information content is high. The results show how we can move toward an open combat system architecture by offloading low-level command and decision (C&D) functions to the workstations. This reduces the load placed on AEGIS C&D system computing and memory resources. Higher-level functions unique to the watchstations can also be implemented in the workstation equipment.



GAINING CONSENSUS ON COMBAT SYSTEM REQUIREMENTS

A new acquisition framework means changes on the requirements side as well. There are many areas today in which requirements are uncertain or unsettled. This is due in part to the end of the cold war era and the transition to a new order in which the world continues to be dangerous, but we are left without a clear adversary or challenge.

Shown here (at left) is the structure of information needed to define requirements for a control backbone system. Corresponding design topics or subsystems are shown at the right.

Similar vugraphs could be constructed for the other backbone systems identified; i.e., external information management and action path clusters. With respect to the former, it is noted that no consensus set of *Situational Awareness* requirements for surface combatants exists. Similarly, with respect to action path clusters, a consensus set of requirements is needed for integration of hardkill and softkill capabilities in the area of self-defense combat systems.

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SUMMARY OF KEY POINTS

Key points made throughout this document are recounted here. We have tried to emphasize that any approach that fails to consider the total surface combatant as a single entity (or supersystem) is simply not adequate as a way of doing business.

Several important combat system engineering principles are reflected in the functional architecture considered in this report. They include

- The fundamental building blocks for the construction are warfighting paths, reflecting the purpose of the combat system.
- The construction provides for information and resource sharing, which are crucial to integration and affordability properties of combat system.
- The construction provides for full coordination, functionally complete and conforming to the expected battle organization.
- Two levels of coordination are present. Warfare mission area coordination is focused on fire control tasks, while unit level coordination provides for interaction with external agencies; i.e., with other ships and commands.

A key aspect of modern technology is the potential for gains in capability and affordability through sharing of resources across subsystem and element boundaries. A wide variety of resources (sensors, computers and displays, magazines, and launchers) can be shared in this way. For this reason, the key problems of design are moving upward in the hierarchy of systems.

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For an enterprise with lofty goals, plans must be formulated around a vision expressing the ultimate purpose and strategy of the enterprise. Such a vision brings the main factors governing conduct of the enterprise into focus and helps mobilize available resources to achieve success. Since the ultimate purpose of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) revolves around surface ship combat systems, our vision is one of future combat systems.

This report considers a vision framework for development of future surface ship combat systems that are ever more capable and affordable, incorporating new technologies, and supporting implementation of new naval maritime strategies. The structure of the report reflects our idea of what constitutes a useful vision. This involves at least four elements, which should form a consistent and balanced set: information about end-use requirements for the combat system, a functional model (or architecture) indicating how the system will carry out its tasks, an organizational model indicating how system development tasks can be accomplished, and a resource architecture providing for generation and control of all capital resources needed to build the system—funding, technology, people, plant, and procedures.

The report begins with a review of the work that has gone into creating a functional architecture for surface ship combat systems. The resulting *vision architecture* serves as a framework for engineering of future combat systems. It then proceeds to explore implications of that framework for the way in which we organize and do business in the development of advanced combat systems.

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